Guild, Holy Apostles Episcopal Church, West Duluth, Minn., on "The U. S. Weather Bureau and its work"; also November 30, 1907, before the Saturday Club, at the Duluth Carnegie Library Building, on "The Weather Bureau".

Mr. M. R. Sanford, August 9, 1907, before the summer school of Syracuse University, on "The work of the Weather Bureau".

Mr. R. H. Sullivan, November 21, 1907, before the Wichita, Kans., Chamber of Commerce, on "The work of the Weather Bureau and its relation to public interests".

Mr. J. F. Voorhees, of the Knoxville, Tenn., office, October 10, 1907, before the Farragut School, Concord, Tenn., on "How forecasts are made and distributed".

Mr. E. C. Vose, November 15, 1907, before the physical geography class of the Concord, N. H., High School, on "The work and usefulness of the Weather Bureau".

Classes from universities, colleges, schools, and academies have visited Weather Bureau offices to study the instruments and equipment and receive informal instruction, as reported from the following stations:

Albany, N. Y., June 8, 1907, the physical geography class from the La Salle Institute of Troy; also November 14, 1907, a class from the Teachers' Training School of Albany; also November 23, 1907, the physical geography class from the Union School, Rhinebeck, N. Y.

Baker City, Oreg., October 30, 1907, the class in physical geography from the local high school.

Dubuque, Iowa, October 18, 1907, the sixth grade pupils of the Prescott School; also October 25, 1907, the sixth and seventh grade pupils of the Jackson School.

Duluth, Minn., July 23, 1907, a class from the Superior, Wis., State Normal School; also July 25, 1907, a class from the Duluth State Normal School.

Huron, S. Dak., July 25, 1907, a class from the summer school of Huron College.

Los Angeles, Cal., October 15, 16, and 30, 1907, the physical geography class of the Hollywood, Cal., high school, in three sections.

Philadelphia, Pa., March 14 and 16, 1907, classes from the Pennsylvania State University.

Salt Lake City, Utah, September 16, 1907, a class from Lafayette school.

Seattle, Wash., November 14, 1906, a class in physical geography from Ballard High School; January 11, 1907, a class in physical geography from the Franklin High School; April 19 and 24, classes in physical geography, and April 30 a class in elementary meteorology from the Seattle High School.

Syracuse, N. Y., July 19, 1907, the class in physical geography from the summer school of Syracuse University.

A UNIVERSAL SEISMOGRAPH FOR HORIZONTAL MOTION AND NOTES ON THE REQUIREMENTS THAT MUST BE SATISFIED.[1]

By C. F. MARVIN, Professor of Meteorology.

If we try to analyze and represent graphically the movements of the ground, such as result from seismic activity of different kinds and under different conditions, we find that we require several different diagrams, something like those shown in fig. 1.

At 1 are represented the minute motions of the ground, of small magnitude and short duration, such as might be produced by the passage of a heavy car or train; this might even represent a slight shock from a nearby local earthquake, of sufficient intensity to attract the attention of a few people, one that would be recorded by a seismograph of high magnification, as little more than a mere thickening of the line of the recording stylus or photographic trace. The short transverse dashes along the line are intended to mark the minutes of time, and the same time scale is used in the succeeding diagrams.

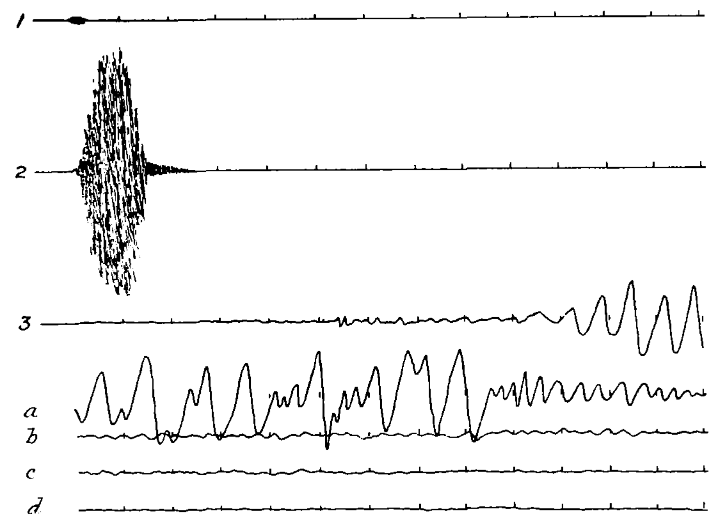

FIG. 1.—Diagrams of different species of ground vibrations.

At 2 we attempt to show, in relative characteristics, a destructive earthquake—such for example, as the earthquake in California in 1906. The time scale is too short to give more than a very general idea of the motion. A multitude of wave vibrations of short period and of great amplitude, as compared with those in 1, are crowded into a short period of time. Practically no details can be made out from such a record as this.

Finally at 3, with continuations of the record at *a*, *b*, *c*, and *d*, for lack of adequate length in a single line, we show the kind of record that will be obtained at a distance of 1000 miles or more from the origin of any great disturbance. As already stated, the time scales are the same thruout the several records, and the amplitudes may be taken to be half size, at least for the larger waves. The smallest tremors are of very great importance in seismic records, and these are greatly exaggerated in the diagrams simply to make them apparent under the scale adopted in the figure.

The three diagrams thus described represent what we may regard as the three limiting classes of shocks. It is plain that one class merges imperceptibly into the other in proportion to the intensity of the disturbance and the distance from the origin at which the record is made. Such diagrams as these may be regarded as representative of one of the two components of horizontal motion, whereas a third set is necessary for the vertical motion, and, in some cases, there may be tilting and twisting motions, all of which require careful consideration.

The problem presented to the instrumental seismologist is to devise and design an instrument or instruments that will record these several degrees of motions in a satisfactory manner. It would be of great interest, at this point, to describe the more important seismographs now in extensive use to meet this demand. To do so, however, even in the briefest manner, would require much more time and space than are available, and it seems best to pass at once to the description of the new forms, recognizing that the present work marks, perhaps, only a step in the evolution and development of the seismograph toward which so much has been already contributed by Zoellner, Ewing, Milne, Gray, Vicentini, von Rebeur-Paschwitz, Omori, Wiechert, Galitzin, and many others.

It may fairly be said that at the present time none of the existing instruments are adapted to register all kinds of earthquake motion. If we wish to record microseismic motions we must get one sort of instrument. A different instrument is

[1] The substance of this paper was presented at the Chicago meeting of the American Association for the Advancement of Science, December 31, 1907.

required for the satisfactory registration of large, distant disturbances. Still a third type of instrument is required for damaging or destructive shocks, and the existing instruments of the first two types, if not completely wrecked when subjected to destructive shocks, at least are seriously disordered, in most cases, and their records falsified and interrupted. If one sets out to equip a seismological observatory, he finds himself obliged to install a large number of instruments. Not only must these be of different types, adapted to the different degrees of intensity and character of earthquake motion, but, in many cases at least, two instruments of each type are necessary, since we have two components of horizontal motion to register, and the horizontal pendulum type of instrument can record only one component of motion. Mention has already been made of the vertical component of motion. Very few instruments are available for recording this, and the measurement and registration of the vertical motion involves exceptional difficulties, and must be treated in a class by itself. Our attention at present is directed exclusively to instruments for the registration of horizontal motion. Those familiar with the subject generally recognize that seismographs, with few exceptions, are influenced by more than one kind of motion. Seismographs for horizontal motion are all influenced by changes in the direction of the vertical and by the tilting of the ground, as well as by vibratory horizontal displacements, so that we can not certainly tell just how a given record should be interpreted.

Having all these matters in mind, I have undertaken to design a seismograph for horizontal motion that should satisfy all the reasonable demands to a much greater degree than any of the instruments now available. The results obtained with the most perfect instruments are, at the best, somewhat uncertain in details, and, recognizing this, my chief object has been the development of a type of instrument that shall satisfy all reasonable requirements for general observatory work, and from which entirely reliable records can be obtained by the average observer. The special student of any problem is always able to refine his instruments and methods so as to attain results of the highest possible order.

A seismograph consists essentially of three separate and distinct parts, viz:

I. The steady mass, so-called, whose function it is simply to remain stationary during the earthquake.

II. The connecting and transmitting mechanisms between the steady mass and the adjacent ground, whose function it is to transmit and, if necessary, more or less to magnify and to inscribe the motions of the ground; and, finally—

III. The recorder, consisting simply of clock movements, drums, paper, etc., upon which the record is actually inscribed.

There is still a fourth part, which, while often missing and not entirely essential, is nevertheless a valuable adjunct in many high-grade seismographs, namely:

IV. Damping devices. These serve the purpose of limiting and controlling the motions that the steady mass may sometimes acquire.

In the presentation which follows we shall take up these parts in order and shall first discuss in each case the general requirements that must be met and more or less perfectly satisfied, then describe the devices and apparatus designed by me to meet these requirements.

I.—THE STEADY MASS.

General requirements.—In the first place, the whole seismograph, especially the steady mass, must be absolutely earthquake proof when solidly installed and subjected to seismic vibrations of the severest order. Of course no seismograph can measure and record the great displacements of several feet that may occur, for example, in the immediate proximity of a line of faulting or where soft, alluvial, deposits of soil are bodily shifted by large vibrations; but we may reasonably demand that an acceptable seismograph be able to ride thru true vibratory motion of the most severe degree, and to do so without the least disorder or derangement of its functions; in fact, it must faithfully record *all* this motion. At first sight, it may seem almost impossible to construct an instrument that will record truthfully the violent surgings and vibrations of the ground during a great destructive earthquake that lays a whole city in ruins in a few seconds; nevertheless, it is actually easier to construct an instrument for this purpose than it is to produce one that will record equally well the great unfelt vibrations that are propagated to great distances from the origin of a violent disturbance.

It is hardly practicable to enumerate all the requirements that we have aimed to satisfy in this new instrument, but we have had a primary regard for all such questions as facility of manufacture and installation; immunity from disturbing influences of the immediate environment, such as temperature, surface tilting, etc.; convenience of manipulation, adjustment, maintenance, and general infallibility of registration, etc.; and finally, the question of cost has received due consideration. In respect to this I may say that a long experience with many classes of instruments has thoroly convinced me that the man who rejects a carefully designed and manufactured piece of apparatus because it costs rather more than something cheap, which may, perhaps, seem good enough, is doomed to disappointment. The best we can do is pretty certain to fail sooner or later, and the failures always come at some critical time when failure is most disastrous. Cheap apparatus is frequently replaced at a later period by something better, thus greatly enhancing the total outlay with less satisfactory results.

Assuming that the reader is familiar with the general elements of seismic apparatus, I may say that the steady mass is, in a certain sense, the basis of the whole instrument. It is impracticable to discuss here the kinetic conditions that must be satisfied in the design of this part of the apparatus, but I can not emphasize too strongly the primary necessity that the steady mass be *free to remain at rest* thruout *all* portions of *any* earthquake. If we examine many of the existing instruments we find it impossible for the steady mass to remain at rest, except only for motions of very small amplitude. In most of the photographic recorders—of the horizontal-pendulum type, for example—the steady mass is carried on a very short strut, or moment arm. This construction not only introduces large angular motions of the strut as a result of moderate relative movements of the ground and steady mass; but even with slight deflections the pendulum is largely influenced by motion at right angles to its axis; that is to say, the instrument records movements which it is not supposed to register.

Again, probably all the instruments now employed in the registration of microseismic motion, if not open to the criticism just made, are, nevertheless, so trammeled with stops, or bumpers, that the steady mass is free to remain at rest only for very small displacements of the ground. This is especially necessary in instruments with mechanical registration, and arises from the fact that the delicate mechanisms employed to magnify the motions from one hundred to two hundred or more times form a delicate system of linkages which in reality can operate only over a very limited range, and are likely to be wrecked or seriously deranged by motions beyond this range. In all these instruments, therefore, the steady mass, during the stronger motions of the ground, is bumped into and buffeted here and there by the stops or buffers on the apparatus, and the records made at such a time are, of course, rendered valueless. It is a very unsatisfactory excuse to make that instruments of this class are not designed to record the larger movements of an earthquake.

In order that the steady mass may be as free as possible to remain at rest for all kinds of earthquake motion it must be mounted upon a relatively long strut, or moment arm, or support. By "long" in this connection, I mean a distance of two or three feet, at the least. Supports of much greater length may easily be employed and possess very great advantages in other respects, which will be discust later.

Two types of steady mass, briefly described.[2]—It seems advisable, at this point, briefly to describe two types of steady mass that seem best adapted to meet all the possible requirements. This will give the reader a mental picture that will be of great assistance in the further presentation of the general requirements. These types are shown diagrammatically in figs. 2 and 3.

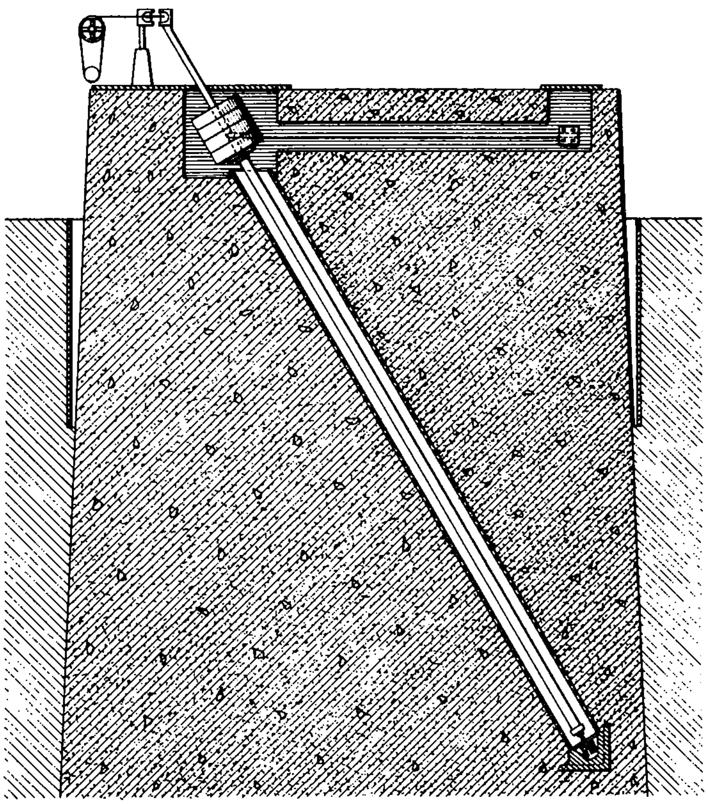

FIG. 2.—Inverted horizontal pendulum seismograph, Marvin system.

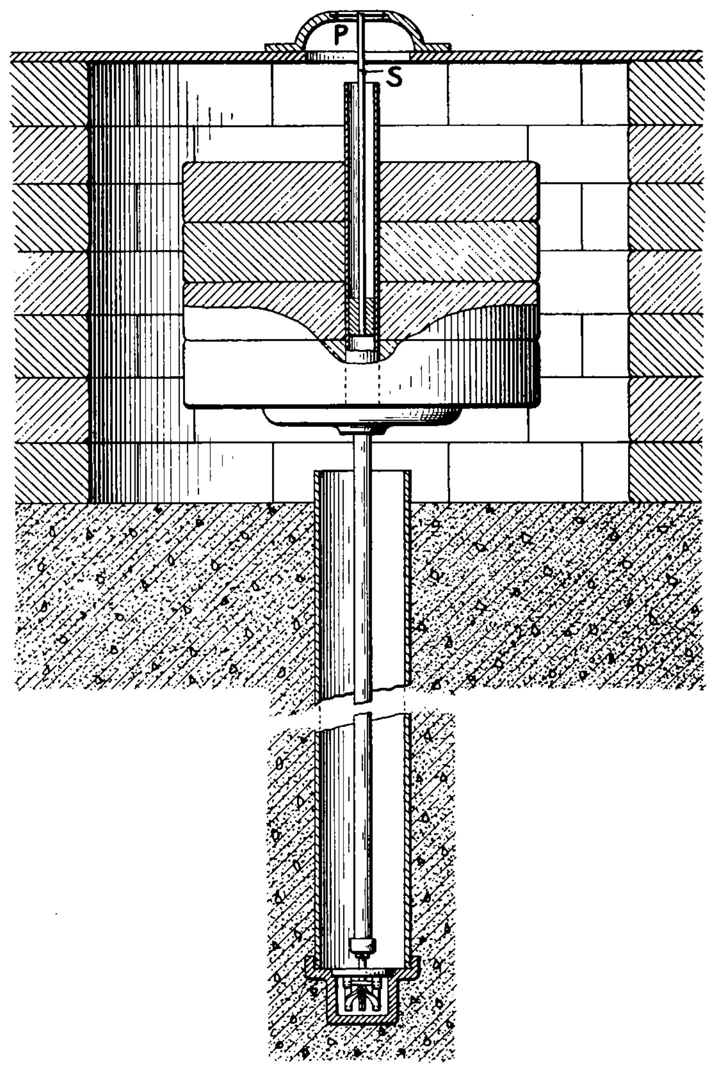

FIG. 3.—Inverted astatic pendulum diagrammatic, Marvin system.

The first form is simply an inverted horizontal pendulum. The object especially sought in the adoption of this construction is to secure relatively large dimensions and, at the same time, to escape, as far as possible, disturbing influences due to temperature and lack of solidity and rigidity. This type of pendulum is peculiarly suited to what we may call absolute measurements of large vibrations, because the highest accuracy of measurement becomes possible owing to the very long period that it seems practicable to realize in this construction. As the instrument is chiefly relied upon for large motions only a low scale of magnification will be utilized.

The second type of steady mass is better adapted to the ordinary registration of earthquakes at numerous stations and for general seismological work. It consists of an inverted pendulum, that is, a heavy mass on the top end of a strut supported at its bottom end on a suitable form of frictionless pivot. The mass at the top end is prevented from wobbling about by the reaction of a suitable spring, S, which causes it to stand quite erect, and, when disturbed, to oscillate freely about a definite position of rest. Any reasonable range of motion may be provided for.

Period of the steady mass.—Referring particularly to the last-described arrangement, we now have mentally before us a steady mass, which, so far as its mountings and immediate environment are concerned, is free to remain at rest during any earthquake motion. The question is whether it will actually do so. This will depend almost entirely upon its period of oscillation. When the ground and pier move to and fro with seismic vibration, the pivot-point support underneath the steady mass, and likewise the fixt top end of the spring S are displaced from their positions of equilibrium, and there is immediately set up a reaction of the spring which tends to make the steady mass follow after the spring. If, now, the force of restitution exerted by the spring is very small as compared to the inertia of the steady mass, the latter will move under the action of the spring only very slowly, that is, its free period of oscillation will be very long. If now, at the same time the seismic vibrations of the ground and pier are relatively rapid, it is very plain that the steady mass can move only very slightly under the influence of the spring and the vibrations of its pivot support before the directions of the motion of the ground and the influence of the spring are reversed. In other words, the steady mass remains very nearly at rest only when the period of the ground vibrations is very short as compared with that of the steady mass. This requirement is easily satisfied in the case of damaging or destructive shocks, as in such cases the periods of the motions to be dealt with are mostly only one or two seconds, or even fractions of a second; and it is very easy to get a period of fifteen or twenty seconds for the steady mass—that is ten to fifteen times as long as the periods of the disturbance. For this reason it is much easier to record accu-

[2] A detailed description of the two types of steady mass is given below.

rately the ground motions in destructive earthquakes than to record the large, slow motions that are propagated to great distances from an origin. In these latter cases the ground vibration may often have a period of from ten to thirty seconds, or even longer, which coincides so nearly with the natural period of the steady mass that the latter at once follows, systematically, all the disturbing vibrations. The steady mass in fact is set into violent oscillation and its record falsified. To avoid this difficulty we should lengthen the period of the steady mass to, say, two hundred or three hundred seconds. This, however, introduces new difficulties, and steady masses with periods of more than sixty to ninety seconds are not yet in successful use.

While the steady mass, for the reasons just explained, may sometimes fail to remain at rest, yet the earthquake motion is so complex and the period changes in such an irregular manner that the records are only partially impaired. To overcome this difficulty resort must be had to what is called damping, which will be more fully discust under Section IV.

Weight or inertia of the steady mass.—The mass of matter which must be concentrated in the steady mass depends on the period of the pendulum, the resistance to be overcome at the pivots or other connections with the pendulum, and the work involved in producing the desired record. In the latest photographic recorders made by Bosch a mass of 100 grams entirely suffices, and the motions are controlled by a simple air-damping device.

A vastly greater mass is necessary if mechanical registration is employed, and in this case the amount required depends upon the magnification and the method of registration. With mechanical recorders magnifying 200 times Wiechert employs a steady mass weighing just about one ton (2,200 pounds). Probably there is no method of mechanical registration so delicate and so nearly frictionless as that of writing by means of a very light stylus upon the smoked surface of glass or paper. Exceedingly fine lines can be made and the minutest details are perfectly reproduced in the record. If the period is from twenty to thirty seconds a steady mass of twenty to fifty pounds is necessary to inscribe a record of this kind with a magnification of ten to twenty times and without damping. Damping could not be used on such a pendulum unless the period was reduced below twenty seconds, as the unavoidable friction would itself damp the pendulum about as much as would be allowable.

I have made quite an extensive investigation into the force required to inscribe smoked paper records, and have ascertained about the limit beyond which we can not go in practical work. The resistance is primarily proportional to the pressure exerted by the stylus and depends very little upon the thickness of the soot coating. If the soot coating is too heavy the stylus will not inscribe a deep line, but will ride partly on top of the soot; while a thinner coating will be wholly removed with about the same resistance. One must, therefore, adopt a sort of standard thickness of soot. In my own case, I require a coating sufficiently dense to yield a good strong photographic reproduction of any records I may obtain. Such a coating may be rather thin and perceptibly translucent, after varnishing, when held up to the light.

The stylus required to write a reasonably satisfactory record in these cases must exert a pressure at its writing point of not less than one or one and two-tenths milligrams. The force required to move such a stylus sideways varies considerably, as may easily be understood, but it is very close to one milligram, possibly a little less.

I have measured the pressure and force required over a wide range of conditions, and have been surprised to find that the force required to push the stylus is only a little less than the pressure exerted at its point; that is, from 0.8 to 0.9 of the pressure. This signifies a very high coefficient of friction, but the action of the stylus in plowing away the soot is not quite analogous to ordinary cases of friction.

I have published in the MONTHLY WEATHER REVIEW for May, 1906,[3] methods of further reducing the friction by the influence of minute vibrations, which keep the point of the stylus in a continual state of tremor. By this method the pressure of the stylus can be reduced to from 0.7 to 0.8 milligram, and the resulting line, owing to the minute tremors, will be better than the line produced by the heavier stylus and with distinctly less friction; but long experience shows it is difficult to maintain the vibrations at just the right period and intensity. Little changes come in at times, and, in some cases, the action of the vibration influences the pendulum itself and induces wave motions that vitiate the record.

As the friction at the stylus is generally of far greater influence in damping the pendulum than the unavoidable friction at the pivots, we may form an idea of the mass of matter required to overcome this resistance under given conditions.

Thus far we have considered chiefly the resistance to be overcome. The source of power to overcome the resistance is, in every case, the *force of restitution* of the steady mass. This force of restitution is primarily a function of the period of the pendulum. The period, therefore, becomes of great importance in this connection. If the pendulum is displaced a small amount from its position of rest, and if the friction at the stylus and at other points is greater than the force of restitution corresponding to the given amount of displacement, then the pendulum will be unable to return to its position of rest. This state of affairs can easily be realized by simple experiments with a seismograph with mechanical registration.

The force of restitution in any given case is

$$f = W \sin i ,$$

where W is the mass and i the angle of deflection. We may write instead

$$f = W \frac{4\ d}{lT^2},$$

in which d is the displacement at center of percussion, l is the length of the seconds pendulum, and T is the period of the steady mass. If now x is the displacement on the record sheet, and n is the multiplying factor, then $d = \frac{x}{n}$. If f_s is the force of restitution as exerted at the point of stylus, then $f_s = \frac{f}{n}$, whence,

$$f_s = W \frac{4\ x}{lT^2 n^2}.$$

For seismographs with mechanical registration on smoked paper, the weight of the steady mass should, in general, be great enough to give f_s a value rather greater than one milligram, when x is one millimeter.

The writer strongly advocates the use of heavy steady masses and large dimensions for seismic instruments. The little, delicate photographic recorders with steady masses of a few hundred grams and the possibility of motion greatly limited are not suited to real earthquake registration. Their chief utility is to record the slow, diurnal and secular tilting motions of the crust of the earth, resulting from tidal stresses and other causes.

Sensitive masses.—In all that precedes great stress is laid upon the necessity that the steady mass be perfectly free to remain at rest, or that if it move at all it do so under some kind of damping control so that its motion may be determinate. This is necessary if we wish to *measure* the amount of earthquake motion. If, however, we wish to ascertain simply that earthquake motion has occurred the best device is not a "steady mass" that shall remain at rest, but what we may call

[3] Vol. XXXIV, p. 214.

a "sensitive mass"; that is, a mass very free to oscillate and with its period so chosen that it synchronizes closely with the kind of earth vibrations it is designed to show. In cases of this kind, exceedingly minute tremors of the ground, if they persist for a few seconds, may suffice to set the "sensitive mass" in relatively very great motion.

Instruments in which this principle is employed have, however, only a rather limited utility.

The two types of steady mass designed by me will now be described in detail.

The inverted horizontal pendulum.—The writer proposes this arrangement of the steady mass in order to realize the longest possible period of free oscillation. For this purpose the dimensions of the pendulum must be as large as possible. But if we give the pendulum large dimensions and build it on the top of the pier, we introduce two new difficulties which largely defeat the objects in view; that is, we are likely to lose rigidity and solidity, which are of the greatest importance, and to introduce uncontrollable temperature differences and other influences which are proportionately exaggerated with the larger dimensions. We therefore build the pendulum as much as possible below ground, and not only do we secure solidity and stability, otherwise unattainable, but the troubles from temperature and other atmospheric influences must be very largely reduced.

A pendulum of this character is peculiarly adapted to register large slow vibrations that form part of the wave motions induced by distant earthquakes. Such an instrument requires only small magnification, and in many particulars it is very easily constructed and maintained. Details of construction will be readily understood from the accompanying figures and description of the second type of pendulum. Some features of the theory of the instrument and limitations upon the development are given below.

The period of vibration of a horizontal pendulum is derived from an equation of this form:

$$T = \frac{2\pi}{\sqrt{g}}\sqrt{\frac{lh}{a}}$$

where l and h are, respectively, the horizontal and vertical arms of the pendulum, while a is a small quantity measuring the slight inclination it is always necessary to give the vertical arm.

It is plain that the value of T is greater the greater we make the product lh and the smaller we make a. The quantity a can not, in general, be made smaller than certain minimum limits. In any case we make a just as small as practicable. For great periods the product lh must be as great as practicable.

Omori, in Japan, employs horizontal pendulums of the greatest periods of any at present in use, sixty seconds or more. The product lh in these cases is, I believe, about 2.65 (meters by meters). By adopting the proposed construction, it is entirely practicable, I think, to increase this product up to six or more, and thus realize the longest practicable periods. The new difficulties introduced by this procedure arise from astronomical and meteorological causes. A long-period pendulum is exceedingly sensitive to variations in the direction of gravitation, and to slow tiltings of the ground due to obscure meteorological and other influences. Only recently an account of a highly important work has been published by O. Hecker [4] upon the influences of the sun and moon upon the horizontal pendulum and the deformation of the crust of the earth. According to the results obtained by Hecker, there is a definite daily variation of a horizontal pendulum, even when sunk to a depth of 25 meters below the surface, which, in extreme cases, may attain a maximum value of 0.05 second. This influence causes the recording stylus of a highly sensitive pendulum to wander slowly from one side of the record sheet to the other, and thus causes difficulties not otherwise encountered in more stable systems. The tidal influences, moreover, are complicated by large and slow tiltings of the ground, due to various causes. All these details require careful consideration in any effort that may be made to realize a very long period for the steady mass. The tidal and tilting influences mark the limits beyond which we can not go in the development of this branch of the work.

The type of steady mass which I am now considering, that is, the inverted horizontal pendulum, will, I believe, enable us to realize the longest possible period of oscillation and still retain a sufficient degree of stability for practical recording. If experience proves that a period of two hundred seconds or more is practicable, then any wave motions that generally occur will be almost perfectly recorded by it; that is to say, such a steady mass will remain almost perfectly at rest, and the indications of such an instrument should constitute the nearest approach we yet have to an absolute measure of the earthquake motion. These conclusions are based on the assumptions that the movements of the ground are literally movements of translation. If the motions are really tiltings of the surface and not translations, then the indications of the long-period steady mass will be very greatly exaggerated and will require to be interpreted upon an entirely different basis than if the motions are translations.

Simple inverted pendulum.—This arrangement of the steady mass seems better adapted than any other for the registration of all kinds of horizontal motions.

Fig. 4 shows in sectional elevation the large instrument with which all the experiments leading to the results set forth in this paper have been carried out.

In this case also the steady mass is built *within* the pier, and is practically wholly inclosed by the latter. When the pit is being excavated for the pier, a post hole is dug beyond for a depth of several feet, and a piece of iron pipe, closed at the bottom, is set up perfectly vertical on a good, strong, footing of concrete. The pier is then built up around the pipe as indicated, and the top covered over by a suitable iron plate which forms the base plate for all the recording apparatus, thus realizing the maximum of solidity, compactness, and accessibility. The strut for the steady mass is made of ordinary iron pipe (steam or water pipe), and terminates at the lower end in a type of universal pivot of ribbon-steel construction. One of these adapted to sustain safely a steady mass of over 2,000 pounds is shown in fig. 5. The iron pipe built in the pier is of such construction that the steady mass and strut with its suspension can be inserted and removed from the pier whenever desired, without the least derangement of the suspension.

This arrangement constitutes, of course, an inverted pendulum, and is in unstable equilibrium. It is rendered astatic by the reaction of a cylindrical steel spring rod S and plate P, arranged exactly as shown in fig. 3.

Wiechert has used very successfully a short, inverted pendulum, but the method employed by him to render the pendulum astatic seems less convenient to arrange and manipulate than the one here shown and does not permit large ranges of motion; moreover I believe it is not so technically correct in its mechanical action.

The lower end of the spring S is intended to be fixt at the center of percussion of the whole steady mass. Under these circumstances its reaction upon the suspended mass coincides as exactly as may be desired with that of the force of gravity, which in this case is to be wholly neutralized; and when the reaction of the spring slightly exceeds the component of gravity the whole mass oscillates more or less slowly upon its pivot in proportion to the excess of the reaction of the spring over the component of gravity. It is necessary, of course, to eliminate friction to the greatest possible degree. The ribbon-steel

[4] Beobachtungen an Horizontalpendeln über die Deformation des Erdkörpers unter dem einfluss von Sonne und Mond. Von O. Hecker. Berlin, 1907.

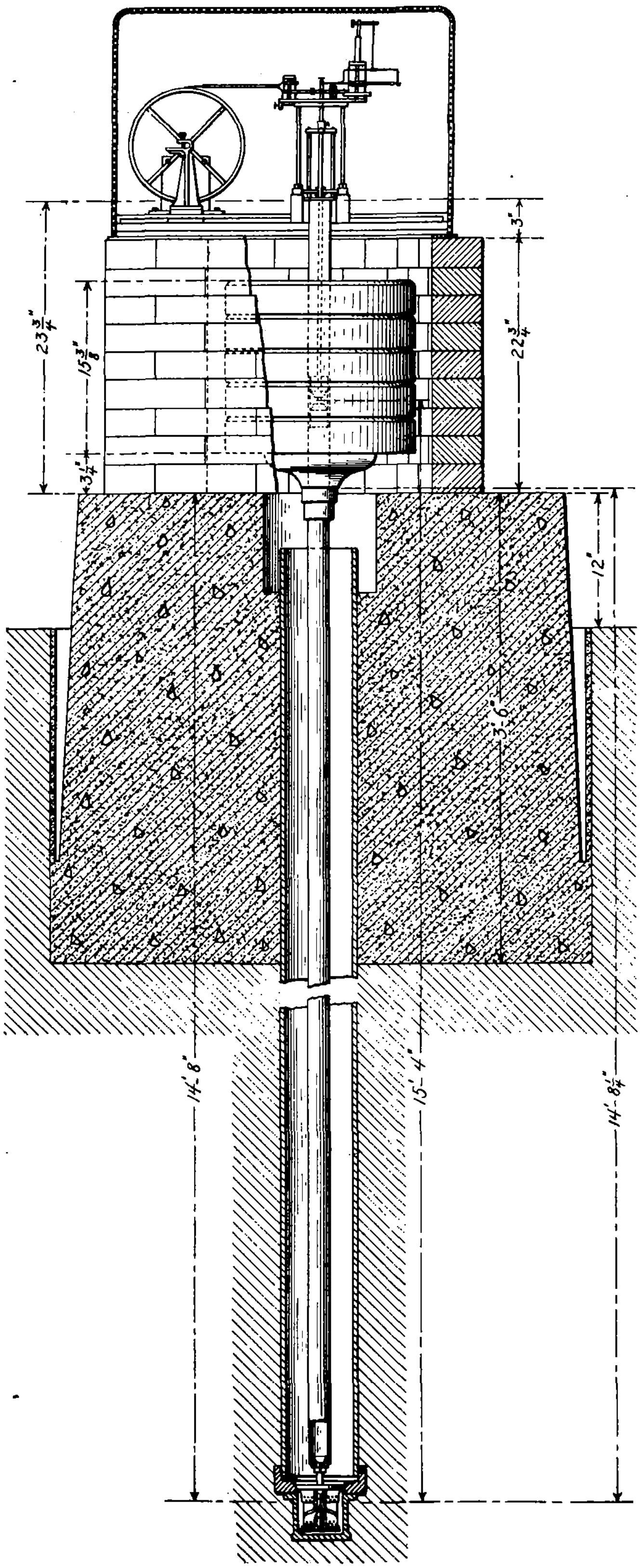

FIG. 4.—Inverted astatic pendulum seismograph, Marvin system.

suspension realizes this in a highly satisfactory manner when great weights are to be supported. It is equally important that the spring S be held at both ends (the top and bottom) in the most approved fashion. At the bottom end the spring is fitted on a slight taper and driven into a massive metal plug. At the top the spring rod seizes, by means of a screw clamp, a flat, tempered-steel disk which, in turn, is securely clamped around its periphery to the top of the pier. Very simple and exceedingly convenient means are provided for centering the steady mass vertically above its pivots. The spring S and plate P must be of the best spring-tempered steel, and a thoro investigation of these has shown most remarkably perfect elastic properties. To realize the benefits of these properties, however, the pieces of steel must be grasped in the most perfect manner possible.

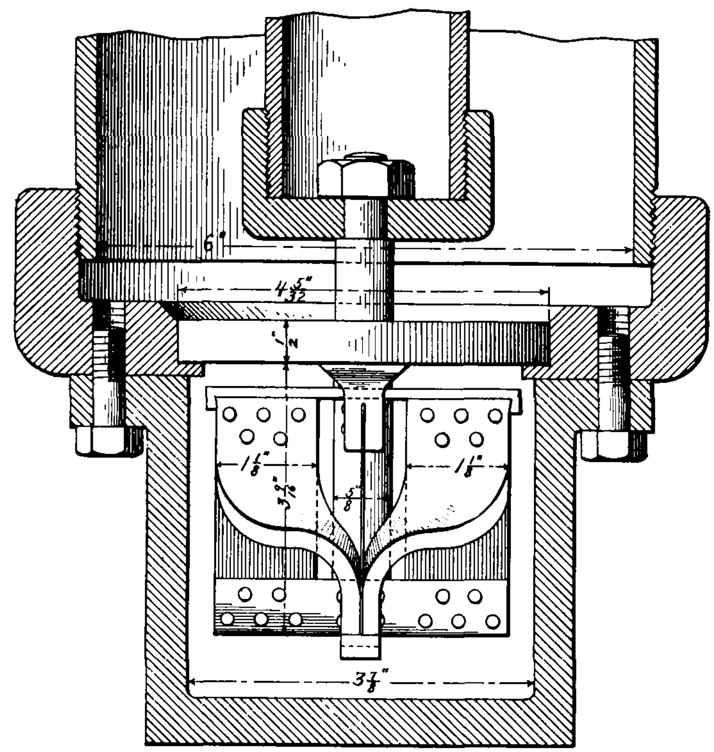

FIG. 5.—Universal pivot, or gimbal, of ribbon-steel construction, Marvin system.

Without any exception, so far as I know, seismographs are constructed to be installed largely above ground, that is, above the floor of the room occupied.

The plan shown here, of building the mountings of the steady mass *in* the pier, rather than *on top of it*, secures, first, a degree of solidity and invariability that are unattainable in the ordinary construction; and, second, the elimination of the unequal changes of temperature in different parts of the apparatus, which cause serious wanderings and driftings of the zero position of exposed seismographs. To exclude dust, insects, etc., and avoid influence of air currents, the exposed mechanisms on the top of the pier can be easily inclosed by a small, close-fitting cover of glass or other material.

A steady mass of this design and arrangement has, as regards earthquake vibrations, almost unlimited freedom of motion in the horizontal plane. It is simply a question as to how much motion we may desire to record on some extreme occasions. A double amplitude of 3 inches has seemed adequate from the information available to the writer, but greater motion can easily be provided for, if necessary.

II. CONNECTION BETWEEN STEADY MASS AND RECORDER.

General requirements.—In all that precedes we have shown how we may arrange and construct a steady mass that is practically earthquake proof and free to remain at rest. The next important step is to devise means whereby we may take off the two horizontal components of motion between the ground and the steady mass, and cause the same to be properly inscribed upon the record. Of course during an earthquake it is chiefly the ground, not the steady mass, that moves, but as we look at the instrument it seems as if the steady mass itself moves, and that form of the expression is simpler and may be used occasionally even tho inexact.

I have already indicated, partly at least, that all existing forms of seismographs fail to meet the requirements of a universal instrument, either because the steady mass is on too short a strut, or, more particularly, because the recording levers and connecting mechanisms can perform their functions under only a very limited range of motions, and generally they are saved from serious injury during strong earthquake action only by the interposition of stops and buffers which restrict the relative motion to very narrow limits.

The steady mass in an instrument of the ordinary construction, with mechanical registration magnifying, say, two hundred times, is not permitted to move more than a few hundredths of an inch, and the multiplying levers are constantly liable to serious disorders that are well understood by those familiar with such instruments.

We have tentatively adopted three inches, or 75 millimeters, as the maximum probable motion that the seismograph will ever be required to record. Any mechanisms connecting the steady mass and the ground must therefore satisfy some such requirements as the following:

(1) Maximum motion to be transmitted, 3 inches (75 millimeters).

(2) The connection must take off only one linear component of motion, and permit perfectly free movement of the steady mass in the component at right angles thereto. It must show no motion, or the least possible, when the motion of the steady mass is strictly at right angles to the component that the connection is designed to transmit.

(3) The power absorbed in transmission, that is, the friction, must be exceedingly small.

(4) The looseness, or shake, or lost motion, in transmission must be *nil* or very small.

(5) The proportion between the motion received and that transmitted must be uniformly the same for large and small motions, and for motions over any part of the range.

(6) Conditions of simplicity, accessibility, adjustability and general convenience of manipulation and maintenance must be satisfied as far as practicable.

Description of high magnification transmission.—Having discarded numerous devices and arrangements I have finally developed the spring-bow and wheel transmission shown in plan and elevation in fig. 6; this seems to meet nearly all the requirements. The topmost extremity of the steady mass terminates in an adjustable pin, *P*. At the top end of *P* two hardened-steel cups, like those shown at *C*, are inserted at right angles to each other, with the one just above the other.

It may be convenient, in some cases, to have the cups *C* adjustable, that is, to screw in and out. A piece of steel music wire, *S*, 0.044 inch in diameter, is sharpened to a needle-like point where it rests in the cup *C* and is bent in the form shown. The hooks *h*, *h′* are formed of any quite fine wire, which is coiled in the manner indicated, and slipt over *S*. The hooks must be fastened, if not coiled tight enough to hold otherwise. *W* is a very light skeleton wheel, mounted on a very free-moving, pivot-pointed axis of the well-known construction, as shown. The rim of the wheel is provided with three grooves, as indicated. While these grooves are really very small, they are relatively very deep compared with the fine silk thread which is run around the grooves. The figure shows an enlarged cross-section of the rim, with dimensions of the grooves marked in units of .001 of an inch. At one side of the wheel a hole is made thru the rim at the bottom of each groove. A piece of ordinary silk sewing thread of the proper length (which can easily be determined) is taken, and its free ends past thru the holes in the outside grooves, one end in each hole; the free ends are then securely knotted together. A loop of the thread is then pulled thru the hole in the bottom of the central groove, leaving the knot on the inside of the rim. The attachment of the thread to the spring-bow by means of the hooks at *h″* and *h‴* is a very simple matter, easily understood. The spring-bow is suspended in a free-moving fashion by means of a thread, as indicated. Finally, the link-suspended, small weight *wt* serves

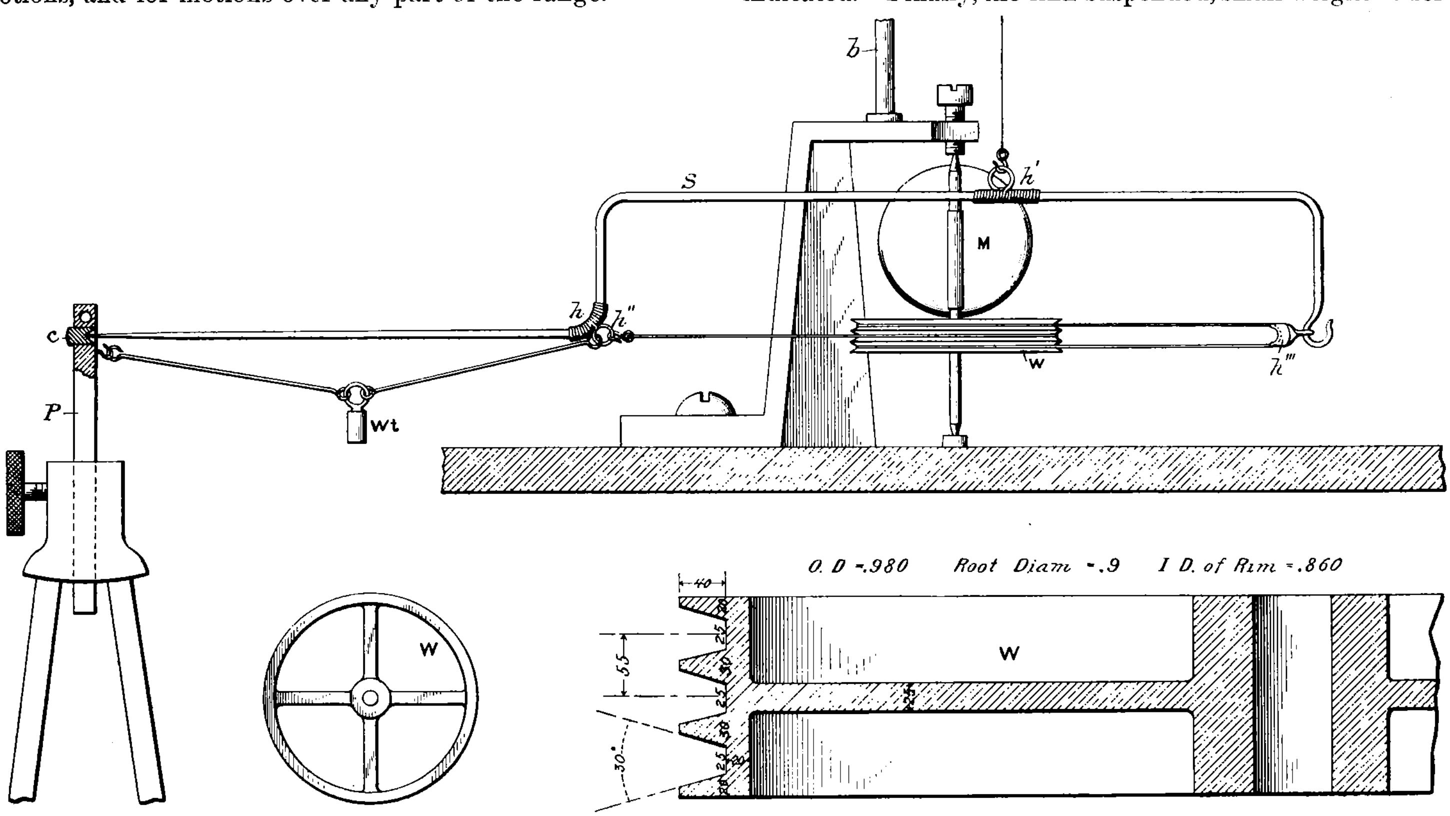

FIG. 6.—Plan and elevation of the spring-bow and wheel transmission, Marvin system.

to keep the point of the spring S in the cup C with a gentle pressure.

The action of this system for taking off the motion is exceedingly smooth and devoid of shake, lost motion, and friction. The arrangement of the double thread in the three grooves secures a perfectly balanced system of internal forces. The action of the spring-bow takes up symmetrically any slight variations of the threads with moisture, etc.; and where the threads parallel each other they are free to slip over the hooks h'' and h''', thus equalizing, approximately, the tension in the two branches. The wheel W, if one inch in diameter, provides for 3.14 inches of motion, and more than one turn of the thread on the wheel is permissible. The distance of the wheel W from P can easily be made sufficiently great to satisfy fully the requirements of (2).

By the aid of this arrangement we accomplish the first step in the process of transmitting the motion of the steady mass to the record. We simply transform one component of the motion into approximately one turn of the wheel W and its staff. It remains now to transfer this motion with the necessary magnification to the record sheet.

Fig. 7 shows a system of levers for this purpose, with a magnification of 120 times. The writer has used this arrangement very successfully for several months past, and it seems to meet all the requirements herein set forth. The distinguishing features of this system are the means provided by which the motions of the levers stop when these reach a certain extreme position, whereas the motion of the wheel W and its connection with the steady mass are in no wise limited by the levers. This is accomplished by exactly the same devices that are employed in the lever-escapement of all ordinary watches, and when the levers are properly constructed there is little to prevent their action from being just as certain and reliable as is demonstrated to be possible in the millions of watches and clocks in common use. A pin, p, on the wheel W' engages a forked opening in the lever l. Underneath the fork of the lever a small pin enters a notch or opening in the flat rim of W'. When the motion of the wheel W' carries the pin p out of the fork in the lever l, the pin below the fork has likewise past out of the notch in the rim, and the lever is prevented by the rim from returning until the return movement of the wheel accomplishes a re-engagement of the pin p and fork. The end of the lever l, opposite the fork, is provided with a delicately pivoted pin, p', which in turn, engages a fork in the short end of the stylus lever L, as seen. Inasmuch as the stylus lever can not sweep over a much wider angle than that embraced within the width of the record sheet, it is necessary that p' also disengage under conditions of extreme motion with high magnification. This is easily effected by making the fork in the end of L of the shape shown, and providing two small bristle brushes, b, b', to limit the motion of L. The lever can not go beyond the brushes, and it can return only when the pin p' is ready to engage the fork.

While these devices perform their function remarkably well and recorded perfectly the great earthquake of December 30, 1907, yet the writer has recently developed the photographic registration to such a state that he regards it decidedly the most advantageous for all records of high magnification (100 to 200). Mechanical records are best under conditions of moderate magnification, two to twenty or thirty times, for example.

III. THE RECORDER.

General requirements.—No seismograph can claim to possess universality that does not provide for a magnification of at least one hundred times, which is necessary in order that the small microseismic motions may be easily distinguished. On the other hand the larger motions may be very easily recorded with a small magnification of two to five times. We must, therefore, have at least two records with low and high magnifications, respectively.

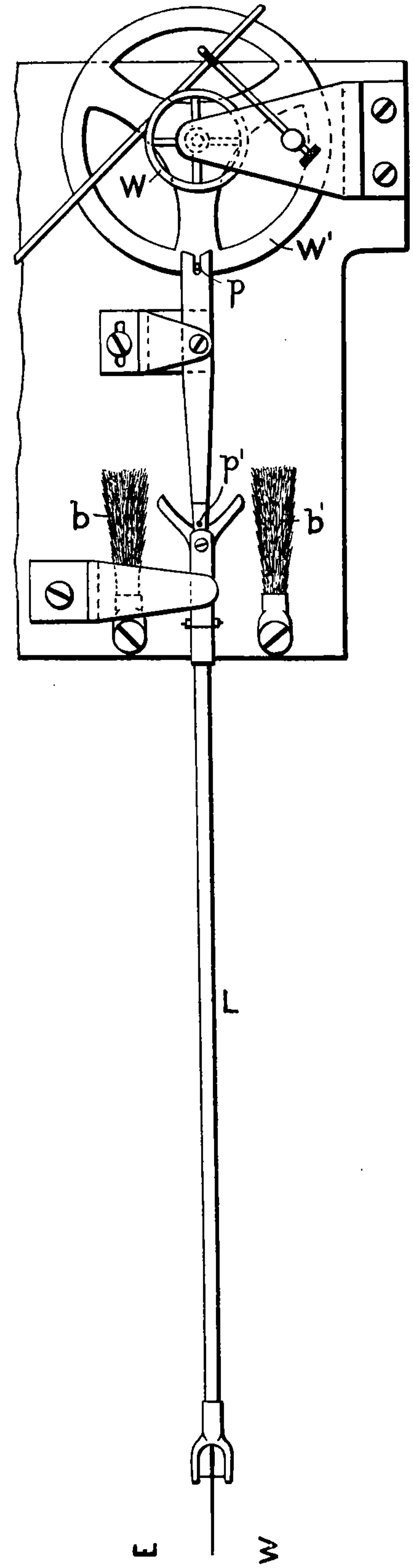

FIG. 7.—Arrangement of levers for transferring motion, Marvin system.

Kind of record.—There are, perhaps, three kinds of records open to choice:

(1) Photographic records.
(2) Records on smoked paper.
(3) Ink records on paper.

The photographic record is, unquestionably, the most elegant and perfect of all, and, under proper arrangements, is available for an almost unlimited range of work. The imponderable pencil of light is, of course, absolutely devoid of friction and imposes no constraint upon the steady mass, whatever the magnification may be. The chief objections to photographic registration are found in the considerations of expense for paper, in some difficulties involved in development of records, and in the fact that the record is invisible until developed.

The smoked-paper records are undoubtedly of the most valuable kind, not only because of their cheapness, but because of the remarkable detail and completeness of the whole result. The chief objection against them lies in the question of the friction, but even this is of no consequence whatever for small magnifications, say ten to twenty times, or less. It is perfectly easy in these cases to employ steady masses of reasonable weight and yet sufficient to render the friction effect unimportant. With higher magnifications, especially of one hundred times and more, and with long periods, the advantages of the smoked-paper records largely vanish, not only because the high magnification requires a steady mass of great weight, but because the multiplying lever system must be compounded, involving several joints and more friction and increased opportunity for lost motion. Finally, there is the difficulty of retaining the perfect freedom of the steady mass while it actuates a lever system of high magnification. All these difficulties vanish completely when we adopt the photographic method of registration for high magnifications and retain the mechanical recorder for low magnifications.

The pen and ink record is quite unavailable for high magnifications, not only because of the fundamental objections given above to the mechanical devices for multiplying the motion, but still further because of the greater friction at the writing point. There are other difficulties of a mechanical nature in providing and maintaining the pens themselves and the ink supply. Quite satisfactory solutions for these difficulties are, however, possible, with magnifications of two to ten times, and the writer has used this system quite extensively. His preference, however, is distinctly in favor of the smoked-paper record, as the danger of losing a record by the stoppage of the ink or otherwise during a destructive earthquake is very much greater with the ink record than in the case of a stylus writing on smoked paper.

In the light of all these considerations, we find ourselves led to the following conclusions, namely, that in a universal seismograph we must provide:

(1) A highly magnified record (one hundred to one hundred and fifty times), which is best realized by photographic processes, which entail no friction and no constraint whatever on the steady mass, and

(2) A slightly magnified record (two to five times, or even full size), of mechanical character, by pen and ink or, preferably, on smoked paper.

Such a system of duplex records from a single steady mass is a perfectly simple and practicable realization of a universal seismograph for horizontal motion. Any seismic vibrations of a reasonable period that are revealed under a magnification of one hundred to one hundred and fifty times, or that do not exceed the 3-inch limit of motion, can hardly fail to be recorded on one or the other of the recorders or on both. If the moving spot of light goes off the sheet, even if it sweeps the entire circumference of the room, no harm is done, and, on the other hand, the pen of the mechanical recorder with small magnification need never go beyond the margins of the sheet. We therefore never fail to get the record in its entirety.

The general arrangement of devices by which all these results are accomplished is shown diagrammatically in fig. 8.

Speed of paper.—Thus far we have said nothing as regards the proper speed of the record sheet. This, however, is very important. What we require here is simply that the waves be drawn out so as to be fairly well separated. On the other hand, too rapid a motion involves a large expenditure of material and labor in maintenance. A speed of 90 centimeters, 35 inches, per hour is a speed commonly used and seems to answer all requirements, except for the case of destructive earthquakes. In such cases the periods of the earth motions are from one-tenth to one-twentieth those in distant earthquakes; hence we must increase the speed of the paper during destructive earthquakes to at least twenty times the ordinary speed.

The limited experience of the writer with damaging or sensible earthquakes does not enable him to decide definitely whether both recorders should be run at a high speed during damaging earthquakes or not. Such considerations as follow indicate a partial answer to this question.

If we take 4 inches as the maximum possible "throw" of the spot of light that can be registered on the photographic record, and assume a magnification of 100, we must have at such times a ground motion of .04 inch. If the period is one-half second, the maximum acceleration is—

$$I = \frac{4\pi^2 a}{t^2} = 6.4 \text{ inches, or } 160 \text{ mm., per sec. per sec.}$$

This result indicates a disturbance of very slight intensity, even tho the highly magnified waves pass clear to the edges of the paper, or beyond, in the photographic record. Of course greater disturbances would be too large to appear on the photographic record under any circumstances. We are, therefore, of the opinion that for damaging shocks there is no necessity for high speed motion on the photographic, or highly magnified, record. The requirements of ordinary observational work are fully met by provision for high speed on the slightly magnified record only. That is to say, whenever there is a fairly strongly-felt earthquake the recording drum for the slightly magnified record must be run at a speed at least twenty times faster than its usual speed. For this purpose the high speed motion must be under the control of one of the numerous forms of seismoscopes, or starters, which set off the high speed motion whenever the intensity of the earthquake motion attains a certain fixt degree. Now the duration of sensible earthquakes is, as a rule, less than one minute. Therefore all reasonable demands will be met if, after the high speed motion has been started, it be stopt after a run of, say, three minutes. That is to say, the drum, having once been set going at the high speed, will automatically resume its slow speed at the expiration of three minutes, or any similar interval that may be judged sufficient. It is a simple matter to meet such a requirement and also to provide that the drum shall automatically assume the high speed and return to the ordinary speed as many times, within reasonable limits, as the circumstances may require.

Summarizing, we find, therefore, that having a perfectly free steady mass we are able to record every species of horizontal vibrations if we provide a set of duplex recorders—one photographic, with high magnification, and the other mechanical, with low magnification, the latter capable of running at a high speed for short runs whenever set off by a mechanical starter of appropriate design.

Additional requirements for satisfactory photographic registration.—The photographic records of earthquakes from ordinary seismographs are all very unsatisfactory. The record may be very fine and sharply inscribed as long as there is no earthquake. The very small earthquake waves are also finely recorded, but just as soon as the waves become large the trace gets fainter and presently vanishes from the record entirely, except at the very extremities of the waves. For a long time the writer regarded this as wholly unavoidable, for

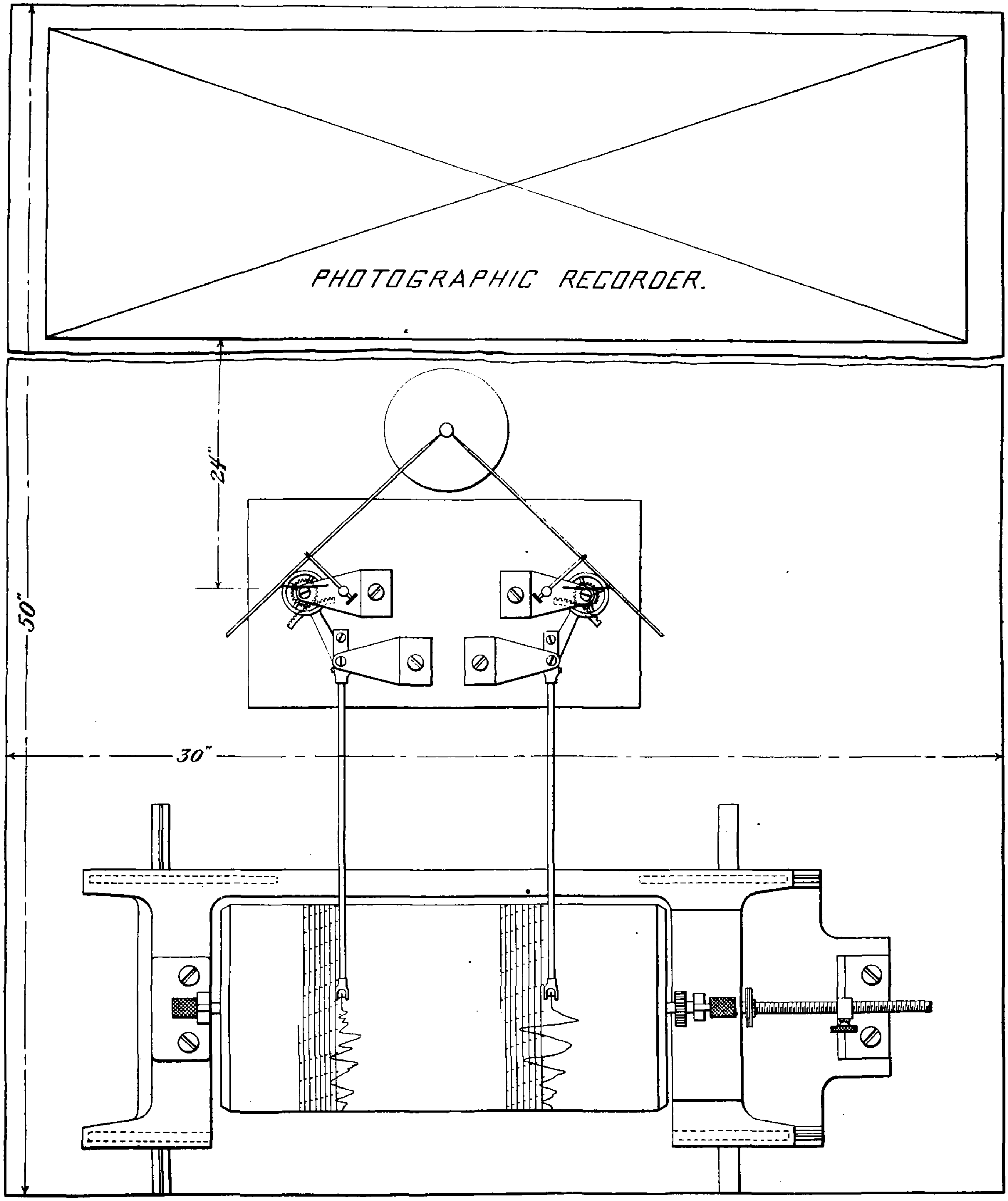

FIG. 8.—Diagrammatic view (plan) of universal seismograph, Marvin system.

some reason imperfectly understood, and he supposed that the photographic film would not take a record of the large wave motion without becoming fogged or blurred when the waves subsided. This idea was at once investigated when he saw the advantages and necessity of using the photographic record in the universal seismograph. The result of the test demonstrated at once that the difficulty lies entirely with the light. The paper will stand many times the range of exposure required. In extreme cases of wave motion the velocity of the spot of light over the paper is something like 300 times as fast as the motion of the paper alone when the spot of light is at rest. Now the photographic record should show any wave that comes within the limits of the sheet, and this requires a light 300 times stronger than necessary just to make the record in the absence of waves.

The chief reason why existing seismographs fail to get a full photographic record arises from the fact that to get the desired magnification the light and the photographic record sheet are placed at a great distance (10 to 15 *feet* in some cases) from the seismograph. A distance of 20 to 24 *inches* suffices in the design herein described, and something like a forty-fold advantage is gained on this account alone in the question of illumination. A great gain is also realized in the matter of sharpness of image, etc. Finally, it is easy to get the necessary intensity of illumination by the use of suitable combinations for concentrating the light from ordinary sources of illumination.

The results and conclusions presented in this paper are not simply speculations, but are based on actual mechanisms and experiments conducted with the large seismograph illustrated in fig. 4. The steady mass weighs about 1,300 pounds and serves to actuate two mechanical records, each with magnification of 120 times. The vertical support of the steady mass was made exceptionally long (total length 17 feet), in order to test and experiment with certain phases of seismograph construction that we have not as yet fully investigated. Numerous records with pen and ink and the highly magnified smoked-paper records have been secured day by day for some two months past, and our conclusions are thus derived from actual experience. A new instrument with the duplex records is under construction and will embody every feature finally perfected and developed in the foregoing analysis of the problem.

Description of recorder.—It seems unnecessary to enter into details concerning the recorders, since such a multitude of devices of this character are in common use on all classes of instruments that it is largely a question of selecting something to one's taste.

After a considerable experience the writer is inclined to prefer for seismic records that form in which the record sheets are in the shape of an endless belt, or ribbon. Seismographs require large, long, record sheets, and this is easily realized in the ribbon or belt form, while at the same time the clock drum can be of relatively small diameter, and thus be easier to handle and drive at a regular rate.

The use of the endless band for the record sheet requires some simple means of joining and easily separating the ends of the sheet. An admirable scheme for this purpose has been suggested by my assistant, Mr. Maring. Four or more small holes are punched in the opposite ends of the sheet, so as to register exactly, and the ends are then overlapt and a very thin and narrow metal ribbon, *m*, laced in and out thru the holes, as indicated in fig. 9. This is admirably suited to the smoked-paper records, as the small metal ribbon offers only the slightest obstruction to the stylus, and when the record has been inscribed the ends can be detached without the slightest obliteration of the record.

Still a different means of joining the ends of the paper and giving an even smoother seam with some other advantages, is also shown in fig. 9. Two gashes *a b*, *a′ b′* are first cut in one end of the paper, and tongues *t* and *t′* formed on the opposite end are interlocked in the manner shown. It is hardly practicable, however, to separate a soot-coated ribbon united in this fashion without defacing the record, but the method is well adapted to ink and photographic records.

A very great economy of paper is realized by the well-known method of traversing the sheet several times with a slight lateral displacement of each succeeding trace. This, however, introduces mechanical difficulties in the design of the clock and drum in order to secure the lateral shift necessary. To the writer it seems decidedly best to mount the clock and drum on a small carriage which itself shifts endwise, rather than to follow the usual construction. Only in this way is it possible to realize the best results, that is, (1) the whole recorder can be made the most compact possible; (2) the drum and its axis can be made most cheaply and of the simplest construction; (3) the clock can most easily drive such a drum smoothly and regularly; (4) the endwise motion can be more easily effected and a greater amount of motion provided for; (5) two components of motion on large records side by side can be obtained on a single drum, thus securing compactness and avoiding unnecessary expense for separate clocks, drums, etc.

A general design for such a recorder is shown in fig. 10. The clock and drum are mounted in definite and positive working relation to each other on the carriage *A*, which runs on the usual small steel balls, giving the easiest kind of motion. The endwise motion is given by the screw *S*, which is connected with a suitable wheel in the clock train. A point of special merit in this arrangement is the peculiar nut employed. This nut is carried on the bracket *B*. The screw *S* passes loosely thru a hole in the top of *B*. A small worm wheel, *W*, is inserted into a recess milled out in the top of *B* in such a manner as to engage the threads of the screw, and thus serve as a nut. A thumbscrew is now provided by means of which the worm wheel can be clamped in its recess, in which case the carriage and drum are locked and can move endwise only as the clock revolves the screw *S*. When the thumbscrew is loosened a part of a turn, the worm wheel is free to revolve, and the drum and carriage can be shifted endwise at pleasure and set in any position desired.

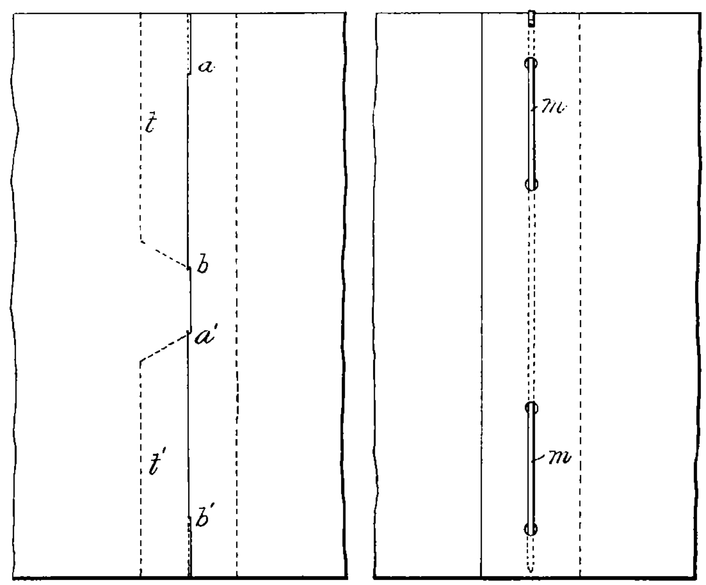

FIG. 9.—Methods of joining the ends of the record sheet.

Two-speed movement of drum.—As already explained, the drum must revolve at a rapid rate (about 0.2 of an inch per *second*) during destructive earthquakes, and at a slow rate (about 0.6 of an inch per *minute*) at other times. To accomplish this alteration of speeds from the slow to the fast and the fast to the slow, we employ a clock with two governors attached to the train. One governor permits the clock to run down at the slow speed; the ordinary balance-wheel and lever escapement, in fact. The other governor ordinarily is held in check, and is released whenever an earthquake occurs of sufficient intensity to require the high speed motion. When this train has run at the high speed for three minutes of time, it automatically stops. The slow speed governor, which has been running all the time, thereupon resumes control of the rate of motion.

The exact form of clock with duplex governor now being constructed will be described at some subsequent time, also the very simple devices employed to start and stop the high speed and mark the time on the record sheets.

IV. DAMPING.

General requirements.—If we fix our attention again on the second type of steady mass previously described, that is, the simple inverted pendulum, we may regard twenty to thirty seconds as a good working period that may be realized. As we have already indicated, such a steady mass will not, ordinarily, remain at rest satisfactorily when subjected to long-period ground motions, and some expedient must be resorted to in order to overcome this difficulty, if possible. With this object in view, the German seismologists, especially, have introduced various methods of damping the motions of the steady mass. We must not regard damping as broadly beneficial; it is more in the nature of a necessary evil. It does not help the steady mass to remain at rest; indeed damping tends to set the steady mass in motion. Nevertheless, the motion thus set up is controlled in such a fashion that under certain assumptions we can compute from the record with more or less exactness the actual motions of the steady mass, or rather the true motions of the ground. The assumptions we are obliged to make do not always fit the facts satisfactorily, and the results are accordingly inexact. Damping, therefore, is to be shunned, rather than otherwise, and used just as sparingly as possible. The only way this can be accomplished is to use a form of steady mass whose period is the longest practicable, consistent with other desirable results.

It is important that a clear idea be formed of the nature of damping in its most desirable form. Damping in any form is some sort of resistance that opposes, but at the same time permits, relative motion between the steady mass and its immediate environment. The resistance may be offered by the motion of blades or paddles submerged in a liquid, for example, or by vanes of appropriate arrangement that fan the air in a certain sense. The resistance may even be derived from electro-magnetic reactions. Instruments in which no particular devices for damping are employed are, nevertheless, often very strongly damped by friction, especially in the levers and linkages and at the point of the stylus employed in magnifying and inscribing the record. This frictional damping is perhaps the most objectionable of all, because it does not conform to any available mathematical law for the computation of the desired results.

Damping to be beneficial must strongly oppose large and rapid motion of the steady mass, but at the same time it must not offer the slightest resistance to the steady mass slowly assuming perfectly its position of equilibrium. This is realized in the resistance of vanes moving either in some liquid, or better in confined air spaces. The appropriate mathematical expression of course affords the most complete and elegant definition of the nature and effect of damping. In the absence of earthquake motion the record traced by a seismograph under some kind of fluid or electro-magnetic damping, when the steady mass has been displaced, is represented by an equation of this form:

$$x = Ae^{-\varepsilon t} \sin \left(\frac{2\pi}{T} + a\right)$$

x is the ordinate of the curve at any time t, ε is the measure of the damping; A and a are constants, T is the period of the damped oscillations.

Broadly speaking, strong damping has the effect on a seismograph of making the magnifying scale of the record depend on the *period* of motion registered, so that only short-period waves, which as a rule are met with only in damaging or felt earthquakes, are registered approximately fully magnified, whereas the slow waves, which are of frequent occurrence in all long-distance earthquakes, are magnified only very slightly, and as a consequence the *small* slow waves may be lost altogether. In some cases the damping may also be a function of the *amplitude* as well as the *period* of the waves, and the mathematics of the problem becomes very complex. These are some of the reasons which make damping objectionable.

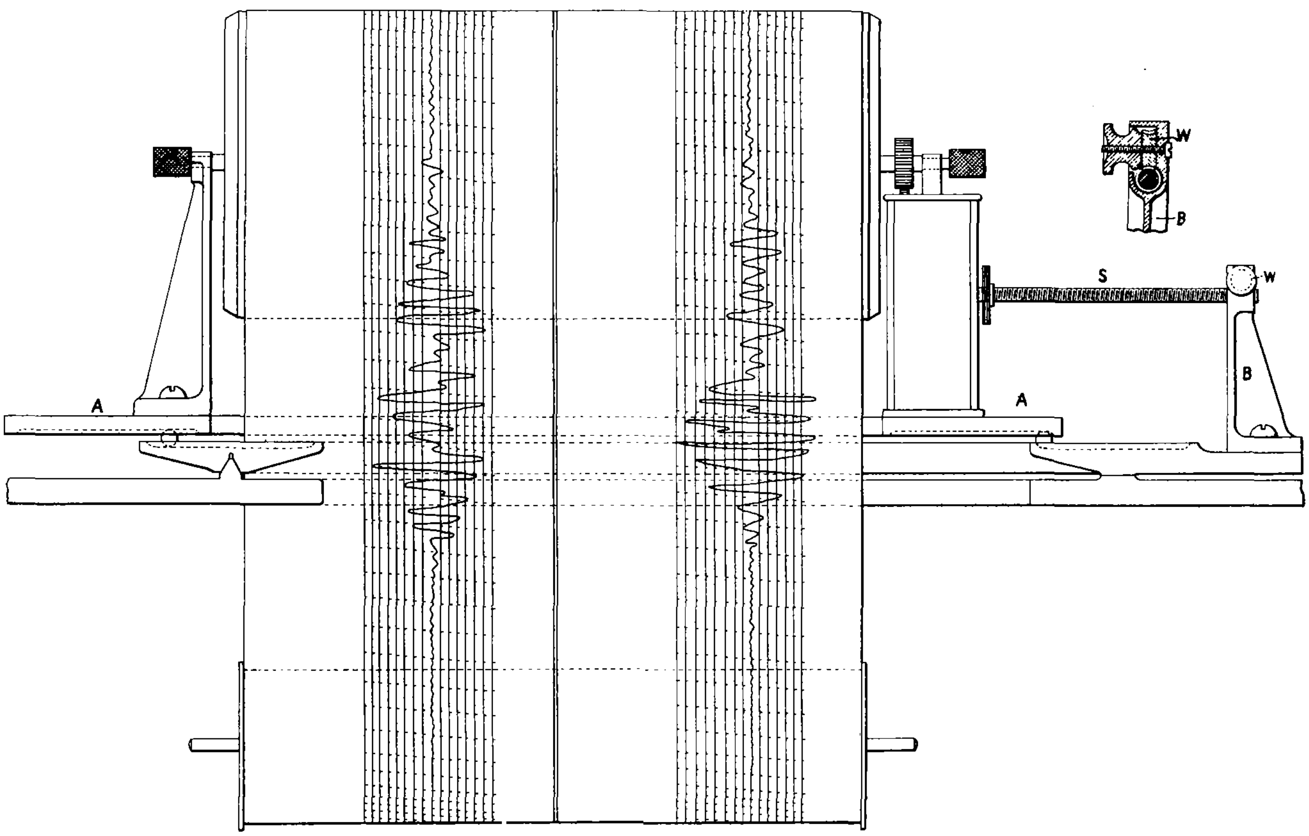

FIG. 10.—Front elevation of recording drum and carriage, Marvin system.

It should be clearly understood that strong damping by *friction* is fundamentally undesirable, since *all* small waves are lost altogether, and large motions are only slightly controlled by the friction. Strong damping, even if of a nature that satisfies the equation given above, is still undesirable, because small *slow* waves are likely to be lost altogether, and larger slow ones are not sufficiently magnified. Nevertheless, when the damping is of this sort, and its magnitude ε in the equation is known, we can compute under certain favorable conditions the actual magnitude of the ground movements. Finally, when friction and damping are both quite small, the instrument is highly sensitive to all minute disturbances, especially motions of nearly its own period. Such motions, however, are likely to be recorded on a greatly exaggerated scale. In general, the deductions and conclusions from a record made on a frictionless instrument of moderate period only slightly damped must be very carefully drawn. The steady mass in these cases acquires certain of the properties of "sensitive masses" previously mentioned.

Galitzin has greatly developed and employed electro-magnetic devices for damping, and for this purpose attaches to the steady mass one or more heavy copper plates, which are free to move between the poles of an electro-magnet. When the magnet is energized, movements of the steady mass are more or less strongly damped by the generation of electric currents in the copper plates. By a suitable disposition of this apparatus the same investigator causes the electric currents thus generated to record photographically the character of the motion. As the *velocity* of the relative motion of the ground and the steady mass, not the *displacement*, is shown by the electric recorder, it seems the data furnished by such records are not in the most convenient form.

The work of the present writer has thus far been directed very largely to the best methods of constructing the seismograph so as to secure what he has called earthquake-proof construction, universality, the longest practicable periods, etc., thereby reducing the necessity for damping to a minimum. It is intended, however, later on to investigate fully the effect of different forms and degrees of damping on actual instruments of the new design.

From a superficial examination of various actual records and effects from ordinary instruments, I find the damping often differs very widely in character from that represented by the logarithmic equation given above, and can not be represented by a simple exponent ε, such as is often employed in the reduction of observations. The subject is one requiring very careful attention.

PUBLICATION OF CLIMATOLOGICAL DATA FROM COOPERATIVE OBSERVERS.

It is anticipated that beginning with the issue of January, 1908, Table II and Table III will be omitted from the MONTHLY WEATHER REVIEW.

Those desiring the data hitherto published in Table II for any State or Territory, or group of States, or for the whole country, may obtain them in the monthly reports of the appropriate section or sections of the Climatological Service of the Weather Bureau. Application for such reports may be addrest to "Chief U. S. Weather Bureau, Washington, D. C., for the Climatological Division", or to the officials in charge at the proper section centers.

THE WEATHER OF THE MONTH.

By Mr. P. C. DAY, Assistant Chief, Division of Meteorological Records.

PRESSURE.

The distribution of mean atmospheric pressure for November, 1907, over the United States and Canada, is graphically shown on Chart VI, and the average values and departures from the normal are shown for each station in Tables I and V.

From October to November there is normally a substantial increase in the sea-level pressure over practically all portions of the United States and Canada, the increase being greatest over the interior districts, owing to the more rapid cooling of the continental area than of the districts near the seacoasts.

The increase in pressure during November over that for October, 1907, was more than twice the average over the central portions of the Plateau district, while over the Lake region, Ohio Valley, and middle Atlantic coast districts there was a pronounced decrease in the mean pressure as compared with the preceding month.

Over practically all districts in the United States from the Lake region and Ohio and lower Mississippi valleys westward to the Pacific the monthly mean pressure exceeded the normal, attaining the maximum over the central Rocky Mountain and Plateau districts, where an average pressure of more than 30.20 inches was maintained. Pressure was also comparatively high over the extreme eastern Canadian Provinces and over the lower Colorado Valley and the surrounding districts of Arizona and California. Over portions of the Lake region and the Atlantic coast districts from New England to Florida there was a small deficiency in pressure. Pressure was also below normal over the Canadian Northwest Territories, where at Edmonton the lowest mean pressure for the month, 29.90 inches, was maintained.

The distribution of pressure was such as to give a decided preponderance of northerly surface winds over the Atlantic and Gulf States, while along the northern border from North Dakota westward southerly winds modified the weather and extended their influence far to the northward over the Canadian Northwest Provinces.

The eastward movements of the areas of high and low pressure across the country were along paths generally south of the normal course, and large portions of the upper Mississippi and Missouri valleys and the slope region were not under the influence of any decided storm movement during the month. As a result of the southward trend of the storm tracks, the wind movement along the Gulf and Atlantic coasts was in excess of the normal, while over the districts from the middle Mississippi Valley westward there was a general diminution of wind movement, which was especially pronounced over the southern slope, where the velocities of the wind ranged from 10 to 40 per cent less than the average.

TEMPERATURE.

The unusual congestion of areas of high and low pressure over the Gulf States and the preponderance of northerly winds, with an excess of cloud and rain, brought unseasonably cold weather over the greater part of Texas and the southern portions of the cotton-growing States. Temperature was also below the normal over the lower Lake region, the Ohio Valley, and the Atlantic coast States from Florida to southern New England. Over the upper Lakes, the upper Mississippi and Missouri valleys, the districts west of the Rocky Mountains, and the Canadian Northwest Territories the average temperature for the month was uniformly above the normal.

Over the States from Minnesota westward to Idaho and in the adjoining Canadian Provinces the average temperature ranged from 6° to 10° above the normal. No severe cold was experienced and outdoor occupations were pursued thruout the month without interruption. Temperature was also somewhat above the normal over central New England and Florida, and it was unusually warm over portions of southern California. Maximum temperatures between 80° and 90° oc-